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Science, policy and place in volcanic disasters: Insights from Montserrat

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ABSTRACT

This paper presents the results of empirical research on Montserrat, in the British West Indies, undertaken in 2008–2010. It highlights the challenges of managing a crisis that evolved from acute to chronic over a period of fifteen years. In particular, the paper considers the evolution of science and policy over a period of fifteen years in its social and cultural context. It discusses the relationship between different types of evolving knowledges, and the interaction between them. Finally, a reflexive model is introduced to draw attention to some of the challenges of managing the science–policy interface under high uncertainty and high stakes.

1. Introduction

During the past 40 years, scientists have been involved in advising governments about volcanic eruptions around the world, often at short notice and in very difficult circumstances (e.g. Tazieff, 1977; Voight, 1990; Newhall and Punongbayan, 1996; Aspinall et al., 2002; Donovan and Oppenheimer, 2012). The importance of volcano monitoring and volcano observatories has also been increasingly recognised (e.g. Tilling, 2008). Nevertheless, the recent court case in L'Aquila has demonstrated the potential legal implications of providing advice under circumstances where the science is highly uncertain: in November 2012, six Italian scientists and a local official were convicted of manslaughter by an Italian court. There were accusations of complicity with political attempts to maintain public calm by underplaying the risk, but there were also questions about the limits of earthquake science and whether or not a low probability of an event suggests that it will not occur (e.g. Marzocchi, 2012). Critically, this incidence has highlighted the issue of risk communication between scientists and governments, as well as with the affected population. This is a question that has also dominated many interdisciplinary research agendas – although the focus has generally been on communication with the public (e.g. Haynes et al., 2008; Bird et al., 2009, 2010; Gaillard, 2008). There is a favoured separation between risk assessment – conducted by scientists – and risk management, which is the purview of governments (e.g. Marzocchi et al., 2012). Fig. 1 presents a simplified conceptual representation of this process, taking as its basis a typical "linear model" approach to science and policy (e.g. Beck, 2011).

There are a number of issues that complicate the schematic in Fig. 1 – including the social context and ramifications of scientific advice, and the potentially very high levels of scientific uncertainty involved. In addition, the role of volcano observatories and advisory groups in many governmental structures

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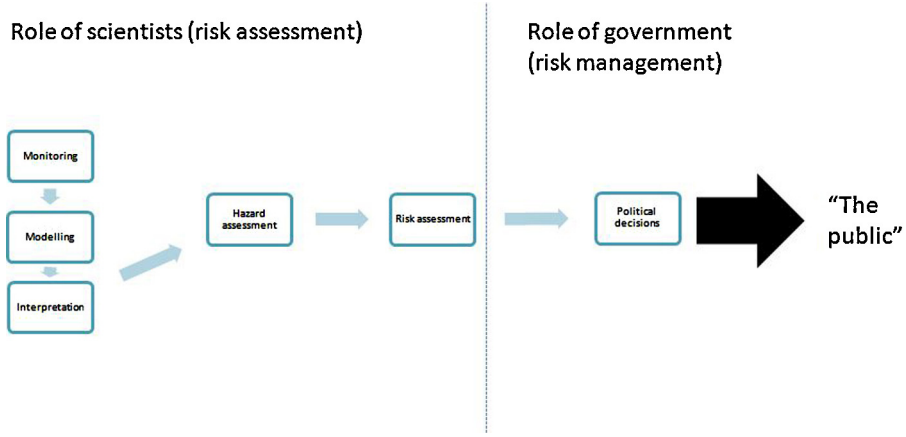

Fig. 1 – Traditional linear approach to science and policy on volcanoes.

requires them to undertake outreach, write public reports and participate in setting alert levels and hazard zonation. All of these activities are critical in volcano observatories, yet all of them involve an interaction of sorts with the public. Scientists may not be anonymous in their community – and the high stakes of evacuation politics render them vulnerable (e.g. Aspinall and Sparks, 2004; Donovan et al., 2012a). Indeed, risk communication studies have shown very convincingly that scientists are often well trusted and are the preferred source for public education about active volcanoes (Haynes et al., 2008; Bird et al., 2010). There is a moral imperative, then, even where legal ones are not in place, for scientists to get involved in risk communication with the public – and it may very well be part of their job to do so. The cost of this may be that when false alarms occur, or a situation akin to L'Aquila develops, scientists are put in difficult, potentially unjust and very stressful positions. It is critical, therefore, that lessons are learned from past crises, so that the risk communication as well as the act of risk assessment itself are undertaken with security and a full awareness of the political, legal and public contexts.

The weaknesses of the linear model have been described by a number of authors (e.g. Fischer, 2000; Pielke, 2004), particularly in relation to the politicisation of science by scientists and the technical-rational view of scientific knowledge. The latter is significantly undermined by uncertainty and also by the complexities of interaction between knowledge and power (Rayner, 2003; Owens, 2005; Beck, 2011). There are uncomfortable challenges when the linear model is applied in democratic contexts, where participatory and deliberative methods may be needed (e.g. Eden, 1998; Fischer, 2000, 2010; Brown, 2009; Jasanoff, 2005; Hajer and Kesselring, 1999; Owens, 2000; Gaillard and Mercer, 2013). In spite of this criticism, the linear model as an ideal does persist (Owens, 2005; Marzocchi et al., 2012). In analysing the science–policy interface in a volcanic disaster, however, we suggest that not only is the linear model inaccurate in the ways suggested by other authors, it is also not consistent with the experiences of scientists and cultures under scientific and social uncertainty. Indeed, volcanic crises involve the combination, over time, of: shifting political and cultural landscapes as institutions and populations are restructured, moved around and re-identify themselves in the context of the eruptions (Skelton, 2000); developing scientific knowledge (and non-knowledge due to uncertainty) as scientists gather information and data about the volcano; and high stakes. This creates a complex environment in which reflexivity and transparency are critical in opening up the advisory and policy process (Stirling, 2008). In this article, we explore these ideas in the context of the eruptions on Montserrat, British West Indies.

The eruptions of the Soufriere Hills Volcano on Montserrat in the British West Indies began in July 1995. Lava extrusion ceased in March 1998, but recommenced in November 1999 and continued episodically until February 2010 (see Supplementary Table 1). There were no previous eruptions on record, and the capital city, where many of the 13,000 people lived, was located on the flanks of the volcano. During 1995–1998, two thirds of the population left. This was a time of significant political, social and economic upheaval during which there was heavy dependence on scientific advice. We refer to this period as the "acute phase" of the eruption. The period from 1998 to 2010 is referred to as the "chronic phase". During this period, the exclusion zone (approximately two thirds of the island) became well-established, but there were periodic evacuations of areas on its margins. In 1995, the Montserrat Volcano Observatory (MVO) was set up to monitor the volcano. From 1997, regular risk assessments were carried out by a group of international scientists, who were formalised into a Scientific Advisory Committee (SAC) in 2003 (see Supplementary Fig. 1).

This paper will first describe the methods used in data collection and analysis. It then analyses the dialogue between science and policy through the eruption, broadly chronologically. Initially we discuss the acute phase, during which knowledge relationships were built between scientists, officials and the public. We then discuss some of the longer-term issues that arose over the acute and chronic phases. Finally, we examine the implications of a chronic eruption for land-use challenges and also a long-lasting dialogue between science and policy. In each of these time periods, we discuss the complexity introduced by particular social, cultural and political challenges. A detailed timeline and information about the eruptions and the political context are provided as supplementary data to this paper (see also Clay et al., 1999; Pattullo, 2000; Aspinall et al., 2002; Donovan et al., 2013). The paper argues that while linear approaches to science and

policy are attractive, the complexity, uncertainty and social challenges that characterise eruptions suggest that a more reflexive, socially conscious, approach to scientific advice and political decision-making is required.

2. Methods

This paper, which is based on a project investigating the interface between volcanology and policy on Montserrat, uses interviews and participant observation as its main research methods. In total, 62 interviews were carried out with scientists, local officials, church leaders, Montserratians and expatriates during three field seasons from 2008 to 2010. Interviews were semi-structured and ranged in duration from 30 min to 2 h. Participant observation was carried out at the MVO for two ten-week periods (April to June 2008 and March to May 2009), during which time the researcher worked for the observatory as a volunteer. In addition, extensive archival analysis was undertaken, focussing on scientific reports from the period studied (1995–2009), but also involving analysis of newspapers (The Montserrat Reporter and a range of UK papers) and government reports from DfID and the UK Privy Council Judicial Committee. The analysis that follows is based on the combination of these methods. Interviews were recorded and transcribed where possible (dependent on permission), and detailed field notes were taken. Interviewees were selected by their role or through contacts in local institutions (businesses and churches) using a ''snowball'' method. This allowed for a range of interviewees who had experience of eruption management and its societal impacts.

The data were analysed using a coding system, identifying themes that emerged during the interviews and were of interest to the project. These concerned the role of scientific advice, the governmental response to the eruption (both UK and local governments); the development challenges faced by the island; the relationship between Montserrat and the UK and the preparation of the island prior to the eruption. The demographic of the interviewees was evenly distributed between the genders, and the age range was 18–80.

3. Translating information in the acute phase

In this section, we discuss some perspectives on the negotiation of volcanic risk assessment and management in the early acute stage of the eruption (July 1995 to March 1998; see Supplementary Table 1), and the longer-term implications of this for scientists working on the island. In particular, we focus on the early education of the population and government, and the impact that the crisis had on scientists' perception of their role in its social context. We then discuss local reflections on the reasons for difficulties in the risk communication process during the acute phase.

3.1. *Building relationships between scientists and populations*

In the late 1980s, two scientists had produced a report detailing four potential volcanic scenarios that might occur were the Soufriere Hills Volcano on Montserrat to reactivate (the findings were also reported in a scientific publication by Wadge and Isaacs (1988)). It is popularly held that the report was washed into the sea by Hurricane Hugo in 1989; in any case it was largely ignored, given that infrastructure was rebuilt and modernised following the hurricane precisely in some of the zones identified in the report as most at risk from a resumption of volcanic activity. This was the source of extensive criticism after the event (Clay et al., 1999). Some local officials hold a rather more sanguine opinion about the disappearance of the report: ''The bottom line is that the inquiry would have harmed the real estate value of Richmond. So everybody has suffered.'' The development of the island would have been slowed down if there had been any need to move from Plymouth. Furthermore, there is evidence that issues with communication may have been a causal factor:

> Geoff Wadge's paper was a paper... and it was academic. Previous generations of Caribbean politicians were not academics – much more so today ... so I can just imagine the paper arriving on the desk of the Chief Minister ... who would look at it, say ''I can't understand that'', and it would be filed. In fact, when the eruption happened they couldn't find a copy of Geoff Wadge's report on island... It would have been more useful if it had stimulated discussions... So I think that paper should have stimulated some curriculum, at least into the Secondary School, and it didn't. Shortcoming of the government of the time, and the academic nature of the paper. It wasn't designed for that. Local official

This hints at the much broader problem of the uptake of scientific research where it is relevant for governments – there was a ''lack of channels'' (Clay et al., 1999) for the communication of emerging research to policymakers, perhaps particularly in small disciplines that deal with low-probability events. Apart from the Wadge Report, limited monitoring data and some other specialist geological studies, there was relatively little information available at the start of the eruption concerning its likely progression and magnitude. This meant that two types of knowledge acquisition were concurrent: that of volcanologists seeking to understand the geology, geochemistry and geophysics of the volcanic system, and that of citizens who had to learn about hazards and risk. It also meant that the selection and involvement of experts early in the eruption was not clearly structured (Donovan et al., 2013). New institutions had to be formed, both in government and for scientific advice. This was complicated by the pace of the eruptive crisis:

> We'd listen to the scientific advice from the chief scientist, and then ... would have to decide how to respond to that advice, sometimes in very very very fast time. Local official

Possekel (1999) and Clay et al. (1999) both identify complexities in governmental structures as presenting major challenges for managing the eruption. It was a problem that also had a significant impact on the scientists as they tried to secure resources for the new MVO during the late 1990s, and

was exacerbated by the ambiguities in Montserrat's colonial status and identity (Skelton, 2000; Skinner, 2004; Donovan et al., 2013). During this time, too, the scientists had to work hard in communicating the risk to the public. Reports from April 1996 demonstrate their anxiety:

> The scientists believe that this is an extremely serious situation, and that there is a possibility of an explosive eruption of the Soufriere Hills volcano during the next few days. Such an eruption could potentially affect much of the south of Montserrat, and scientists urge that the residents of the evacuated zone move to the safe zone tonight (Wednesday). The safe zone remains safe. (3rd April)

> The scientists at the MVO remain gravely concerned about the current level of activity. (7th April)

> The scientists at the MVO remain gravely concerned about the current level of activity at the Soufriere Hills volcano and therefore urge people still living in the evacuated zone to leave immediately. (12th, 13th, 14th)

Volcanologists were seeking to manage a highly uncertain situation with an inexperienced public. An important achievement in the risk communication process on Montserrat, documented by Haynes et al. (2007), was the acceptance of volcanology as a ''young'' science.

> They would like to know for sure, and they don't understand why, with all the monitoring and all the science that we do, why we can't get it more exact. Senior scientist

Many Montserratians interviewed referred to volcanology as ''uncertain'' or ''inexact'': they were aware that the science could not tell them everything that they wanted to know. This was regarded as frustrating but not the fault of the scientists.

A further issue that was identified was the translation of scientific information into information that was useful to the public:

> We have to transmit that information – but we also have to ourselves go through the necessary step to convert purely scientific observational data into observational data that has a direct bearing on society. Senior scientist

The translation process is complex, not only because of the complexity of the observational data, but also because of the societal context.

> It's quite easy to say we should evacuate everybody when you don't have to suffer the consequences of that, so when you're working in an observatory, you're actually much more conscious of the impact you're gonna have in terms of decision making than if you take the decision from thousands of kilometres away. Senior scientist

> The problem is scientific advice is always seen as being: what's the social implications of it? I don't think we can get away from that. If we just say we're giving scientific advice then someone else has to do that job, and they are just responding to what the scientists say, so you always have to work in that area, and always you have to make sure you're comfortable with what you do. Senior scientist

This can be tied into individual experiences and relationships, and the consequences for social interaction, particularly on a small island:

> Then there's also obviously ... when everything goes right and the volcano's not exploding too much and you don't actually have to evacuate people, people will kind of like you. Senior scientist

Scientists thus have a liminal role: they relay information about the volcano-as-object to the population, but also take in information about the population. The following quotation is from a report in 2007, and demonstrates the long-term perspectives gained by the scientists:

> Authorities need to consider the history of past responses of the population to previous advice... For various reasons, people in Montserrat, and elsewhere, often find it difficult to envisage or accept the possibility of unusual or exceptional volcanic hazards which, from their wider experience, the scientists are aware could happen, and many fail to respond to such precautionary warnings as fully as is desirable. This information should feed back into the decision-making process... Appendix 7, Scientific Advisory Committee Report April 2007.

This act of translating the science not only for communication of the risk, but also for inclusion in a risk assessment for the government resulted in the development of new methods for risk assessment in volcanology (e.g. Aspinall, 1998). This quotation also demonstrates the reflexivity that is involved in responding to different kinds of information within the process of finalising advice.

The acute phase of the eruption was characterised by the development of new institutional structures, legislation and geographical identities, as the population were cast out of Plymouth and forced to leave the island or live in the north (Skelton, 2000; Pattullo, 2000). It also involved the growth of a relationship between scientific communities and Montserratian communities.

> The good thing is that the scientists are always ready to explain... they too, it was a learning experience for them too, because they've never had to deal with people, per se – they had only had to deal with the scientific aspect of it, they'd never had to deal with actual people and the fact that people, how people could be impacted by their closeness to the volcano...as you know quite a number of them have earned their PhDs as a result of the volcano, and they are not the same people. Montserratian

The local knowledge *of the scientists* – not just in terms of knowing the physical geography of the island, but also being aware of more human impacts from the volcano – had an impact on their experience. It also impacted the ways in which

the population viewed them. This is a critical aspect of high-stakes scientific advisory contexts: awareness of the extremity of the shock and its impacts on a society is emotive. As local people became ''amateur volcanologists'', scientists themselves became attached to the island. These complex interactions are an important part of the dialogue between science and society.

3.2. *Cultural perspectives on risk perception*

Interviewees reflected on their understanding of the pre-eruption risk from the volcano:

> Fourteen years ago, if anybody had told us it would be better to build our homes over here in the north, rather than in Plymouth, we'd have said, 'You've got to be joking!' Even when the Wadge report came out in 1986, even if each of us individually, even if 12,000 had got a copy and had read it...when I later build my house up there...even if they say to you, well the volcano might erupt, I'd say, yeah it might, but after I'm dead and gone! Montserratian

This is consistent with the findings of other studies, which have shown that people struggle with conceptualising high impact but low probability events – and that they will put daily concerns about convenience and living costs ahead of such considerations (e.g. Gaillard, 2008). The subsequent process of corporate learning on Montserrat was also discussed by interviewees:

> Until 25 June, people never thought that villages could be taken away, people could have died – mind you, scientists were saying that... but because you just never had the experience...but we learn – that is what life is all about, a learning experience. Montserratian

The experience of a risky event has been shown to improve risk perception for future events (the availability bias; Tversky and Kahneman, 1973), so the lack of precedent on Montserrat made future eruptions difficult to visualise. The events of ''Twenty-five'' (25 June 1997, when 19 people were killed in the exclusion zone) shocked the population and brought them together to grieve (Donovan et al., 2011). One local official on Montserrat commented, when asked what might have been done pre-eruption to prepare Montserrat for the potential eruption, that:

> I've walked across the volcanic crater where the dome now sits...and it was a beautiful valley. I didn't realise it was a volcanic crater. I would guess that 99% of the people in Montserrat didn't know.... We should have known, so I think that there should have been more work done over the years and maybe the scientists who came on and off over the years were guilty of that – that they didn't insist on we'd got to understand the volcanics....

At the same time, he continued:

> It's never erupted in recorded history, ... so there's no culture of remembrance, there's no stories, no songs and no music about the volcano to give people that long-term message... and if you look now at the cultural awakening of Montserrat because of the volcano – now let's hope that that output that that cultural awakening has produced stays with us, goes into folklore... I think that's what was lacking before. Yes, we knew that people remember the earthquakes...but nobody realised they were earthquakes of magma trying to reach the surface – they thought it was in the big fault-line.

This quotation again demonstrates the importance of local knowledge, as enshrined in folklore and memory (e.g. Wisner et al., 2004; Cashman and Cronin, 2008; Paton et al., 2010), in building pre-disaster community resilience. It also demonstrates, importantly, movement in the opposite direction: a lack of initial awareness of the volcano has had impacts on subsequent cultural development.

4. Multilayered cultures of risk during the acute and chronic phases

In this section, we discuss some of the geographical factors that affected the dialogue between science and policy throughout the eruption, focussing particularly on Montserrat's status as a UK Overseas Territory, and the consequences of the eruption for emigration and immigration. Both of these areas had significant impacts on the risk communication process, further demonstrating that the linear model is oversimplified: complex political and geographical structures affect the reception of scientific advice.

4.1. *Colonial complexity and migration*

Scientific advice is also affected by its cultural and political context, both in terms of its institutional framing and its reception by the public. The challenges of appreciating the potential hazards (which requires education from scientists) and accepting the possibility of whole-scale social change (chiefly loss of property, but also possible loss of life), particularly given a lack of preparedness and consequent (unconscious) complacency, engender a very steep learning curve. Unlike hurricanes, which occur relatively frequently in the Caribbean but are over quickly, volcanic eruptions can last years, and like all natural disasters they pose particular problems for small islands (Pelling and Uitto, 2001; Tompkins, 2005). In the case of Montserrat, this was exacerbated by the complexity of the relationship between the UK and the island, which blurred local and colonial geographies of science and governance (Clay et al., 1999; Donovan et al., 2013). The political geography is layered, resulting in a complex geography of risks and risk perceptions between London and Montserrat. In turn, this had a significant impact on the vulnerability and capacity of the islanders, and the science–policy interface, as resources, institutions and laws were managed between nations.

Different cultures respond to risk in different ways (Kahan et al., 2009; Paton et al., 2010). These are most starkly apparent at the occurrence of a sudden shock: the point at which a background risk is realised. The self-styled

knowledge-identities of the population(s) may be completely re-shaped by the event – in Montserrat, this was the case particularly in relation to place names, spaces of social interaction and personal risk priorities. The culturally rich south was destroyed, and houses had to be rebuilt in the undeveloped north. The uncertainty concerning the duration of the eruption was critical in this: once the longevity of the eruption became apparent after 1999, political and institutional changes took on a more permanent form. For example, a seven-constituency system was replaced with a single constituency in April 2001 (prior to that, elections for each evacuated constituency were held in the safe zone). Geographical identities were exchanged – initially through the pairing of towns, but later through purely social networks, such as churches and friendships and through different needs (such as the need to educate children off-island). These motions shaped the ways in which new knowledge was made and replaced the old.

Scientists with a long-term involvement on Montserrat identified the colonial discourses as a major influence on risk communication and the application of science-based policy early in the eruption:

> I think a lot of it has to do with the relationship of Montserrat with the UK government. . .. I think some people felt that the UK government had a hidden agenda. . . that there was always some other agenda. . . that was driving what the scientists were saying, and what certain scientists were saying. Senior scientist

A further issue is considerable lateral variation in personal and societal risk thresholds. These may vary individually, on cultural or historical grounds, for example (Slovic, 2000; Sjoberg, 2000): ''In those territories, economic development can never take off, because every fifty years, on average, each island gets zapped completely [by hurricanes]'' (senior scientist).

Demographic changes also had a significant impact on the risk communication process. The exodus produced by the eruption had created a labour vacuum from the late 1990s:

> We had in government a great challenge because we'd lost many of our senior civil servants – people with a passionate interest in their children's education, who tended to be the better educated people, took them off-island and left their jobs. Local official

This led to an influx of people from other islands into these jobs and to the construction sector – where jobs had been created by the need for housing in the north. There are a thus variety of publics involved in Montserrat's human geography of risk, including a growing number of immigrants from Guyana, Dominica, Jamaica and Trinidad, whose familiarity with the geography of the island is fundamentally different from that of islanders:

> When they say, ''oh it's coming down Gages Wall'', I have no idea where Gages is . . . point out to them where Gages is, because people like us who only come to Belham and take a peek over have probably not been to Cork Hill or those areas – don't tell us ''Tar River'' – means nothing to us. Tell us ''Tar River is over to Antigua''. . . Trinidadian resident of Montserrat

In spite of the population boost, however, there was ambivalence in government, and this led to some political disputes between London and Montserrat.

> The government of Montserrat want to bring back Montserratians. That is not cost effective. . .we have over 2000 non-Montserratians living on the island, who send 95% of their salaries overseas. . . but. . .at the same time as they want to increase the population, the government of Montserrat has just announced more stringent rules for getting your citizenship, which Britain has told them they've got to rescind. Local official

The reluctance of the Montserratian government to embrace newcomers was perhaps part of Montserrat's grieving process: the diaspora left gaping holes in society. It also demonstrates a growing sense of shared identity through the experience of the crisis. There was also a perception that immigration may be used as a means to obtain a UK passport (after seven years), and therefore that the intent of immigrants is not ultimately to help Montserrat – and supporting such immigrants may be challenging in any case.

> They keep saying, ''Oh we need to bring the Montserratians back.'' Where are they going to live? If you can't house the people that are on island – we've still got shelters. The man who was living under a boat I found out about last week, I'm moving into a shelter this week. Local official

This has been complicated by the colonial context (all Overseas Territory citizens became British citizens in May 2002):

> Now, to make it worse, everybody is British, so they should be on par with the British citizen in Britain – and let them – if the Isle of Anglesey had this natural disaster like Montserrat had, let me see them go through the same things that Montserrat went through, because there would be riots in the streets and there would be the press up in arms . . .you can't have a second tier of British citizens. . . Local official

Montserrat's geographical location was clearly identified as a factor in the management of the volcanic risk: out of sight, out of mind. The same local official noted, ''the very fact that we still have shelter spaces is a total, abject, utter disgrace, and a slur on the British government''. Yet, ''we would not have got through the crisis'' without UK aid: Montserrat had little diplomatic prowess early in the eruption, according to a senior local official present prior to the eruption, and that would have made it more difficult to get aid. Scientific institutions providing advice on Montserrat had to negotiate complex colonial political structures as well as communicating with the evolving demographic on the island.

The fact that many scientists involved in advisory processes were British added a further layer of complexity

to the identification and re-identification of the island. The negotiation of the risk that was faced by Montserratians since 1995 has been characterised by the complex intertwining of UK, Montserratian and scientific realisations. Social theories of risk *and of science* can provide important insights into the complexities of local risk realisations, which should feed into disaster management. Different perceptions of risk can also be read into a society – as UK measures of risk such as the Chief Medical Officer's scale, used in SAC reports, were read into a community with entirely different risk experiences.

5. Risk governance and responsibility in the chronic phase

In the years following the resumption of volcanic activity in November 1999 (see Supplementary Table 1), the need to view the eruption as chronic rather than a crisis eventually became clear. However, the episodic nature of the eruptions, the uncertainty surrounding the volcanic activity and the limited land area continued to require reflexive risk management. This section discusses perspectives on the chronic phase and its management. It also notes the prevalent view in the interviews that scientific advice, as the primary basis for decisions, may not be clearly separated from those decisions in practice: populations may view the two as inextricably linked.

Montserrat's colonial status renders it a special case politically: the Governor has ultimate responsibility for internal security. However, he includes the democratically elected politicians, local officials and religious leaders in the discussions, before making a decision to evacuate part of the island. The MVO is expected to advise the National Disaster Preparedness and Response Advisory Committee (NDPRAC), chaired by the Governor, about the volcanic activity, and this leads directly to policy decisions which may have very damaging political implications. One previous governor commented,

> I wanted to act on the side of caution, and to err, if possible, on the side of caution in asking people to move – one responded to the advice, to the report of the scientists, and that was the basis, largely, for our decisions. Clearly the scientists gave advice, but they can't make the decisions – ultimately it's for the civil authorities to make the decisions.

Precaution in volcanic risk management is therefore two-sided: it applies both to protecting safety, and preventing the economic loss of an unnecessary evacuation – a ''lives versus livelihoods'' choice (Douglas and Wildavsky, 1982; Wisner et al., 2004). In this case, erring on the side of caution was considered preferable because of the perceived lack of scientific knowledge about the volcano: a mutation of the precautionary principle applied not to the as-yet-unknown consequences of modernisation, but to governance in a society threatened by scientific uncertainty. It was also a consequence of experience on Montserrat – the nineteen deaths on 25th June 1997, of people who had refused to leave their homes and farms (their livelihood), had a considerable impact on scientists and policymakers.

> The scientists will give the best advice possible, and they will say ''Listen, we are not comfortable with certain things and we don't know what's likely to happen'' ... then the authorities will make a decision based on a precautionary measure ... so that the scientists could monitor a little more, and then if they are satisfied they will move the people back. Local official

In the case of volcanic risk governance on Montserrat, taking high levels of uncertainty and translating it to policy has been a collaborative process between scientists and political officials. Scientists interviewed were aware of this.

> This model of the scientists in one camp, the decision-makers in another, scientists communicate to the decision-makers, who say thank you very much, we'll make a decision – it doesn't happen on Montserrat, and I'm not sure it happens necessarily all that well in a lot of situations. Senior scientist

This sentiment was noted by several interviewees: the boundaries between providing advice and being involved in decision-making were murky because of the high dependence on scientific advice. A further complication is introduced by the colonial context:

> London will inevitably be much more cautious because London's standards of risk management tend to get applied, and the general level of risk that's acceptable to people living in the Caribbean is higher than the general level of risk accepted by people who walk around London, so that you've got different societal understandings of risk, and anyone who wants to develop Montserrat, a stable Montserrat, who comes to Montserrat, is accepting a higher background level of risk anyway as a result of volcanic activity. Local official

This is important because it suggests that there are differences between Montserrat's risk culture and that of London. Officials from London in the early part of the crisis were concerned that the island should be shut down because of the activity. During the chronic phase, however, efforts were made to distinguish between what was appropriate for Montserrat and the temptation to read into Montserrat a risk culture that was London-derived. However, this also raises the important issue of risk tolerance – one that was resisted by some interviewees, who felt it was completely unhelpful.

> I think that the ones that are the most antagonistic feel that the scientists are just guessing. I think that's one end of the spectrum. And then I think that the middle of the road people, like myself, appreciate what they're saying, know that ... it can change because so does the mountain, and therefore we can kind of sympathise with both the government or the Governor and the scientists, because they're kind of caught. And then there's the other end of the

spectrum – people that are petrified of the volcano. Montserratian

This quotation demonstrates the complexity of the knowledge-testing process: it is highly subjective. It also creates anxiety: the anxiety of scientists concerning their liability is clear from reports, particularly from 2002 onwards (when there were several court cases about evacuations). The formalisation of advice into the SAC was largely to gain greater protection, and SAC reports contain a disclaimer, pointing to the government's responsibility for its decisions.

> You start thinking, what is the responsibility of the politicians? And their responsibility, at least to my mind, is . . . there are real risks, so if the volcano is acting up and half the people in the Belham Valley don't think it is because they're in denial or their risk perception either is that the scientists are talking nonsense or that they don't feel there's a risk, but the objective best evidence-based assessment is that there is a high risk, then the government's got the responsibility of protecting those people, so they can't let the risk perception of the people change the decision. . . they might want to factor it in, but they might factor it in in a way that's not necessarily scientifically based. Senior scientist

The technical-rational invocation of evidence-basing sits uneasily with the different kinds of knowledge that are used in the policy process. There is a non-linear relationship involved in weighing often-uncertain scientific evidence with public concerns and political costs. While this is viewed as the purview of governments, scientists were aware of ambiguities and expressed strong views about objectivity in the context of social demands. Others mentioned a different kind of responsibility:

> And the volcano over the years has become a very good excuse – if things don't go right it must be because of the volcano, and at the end of the day it comes down to this: you blame the MVO, you blame the volcano because of the economic situation and so on. Well, if you live on the boundary of the exclusion zone lower down, so that you'll be evacuated if the volcanic activity increases, I'm sorry you have to take responsibility for that. If you don't want to actually handle the possibility of being evacuated again, you have to move to another area. Senior scientist

This demonstrates that even after 15 years of eruptions, there was occasional anxiety between scientists and decision-makers and the public. The frustration inherent in this quotation was expressed by multiple interviewees: managing the responsibility for the volcano and the responsibility for inconveniencing people was challenging. However, in 1995, few people knew that the volcano was active. In 2010, building a house near the exclusion zone boundary might be considered irresponsible. This issue is complicated by the continued immigration of expatriates, since arrival during a volcanic "pause" may mislead people. The increased immigration of the 2000s has required reflexive governance.

6. Conclusions: science, governance and decision-making on Montserrat

This paper has demonstrated that the eruptions on Montserrat raised a number of key issues regarding eruption management and scientific advice more generally. Many volcanoes have exhibited an ability to erupt over decadal scales, and this presents significant challenges for land use, particularly on smaller territories. It also requires a clear definition of the science–policy interface in the context of volcanic risk. The narratives that emerge from our analysis demonstrate that

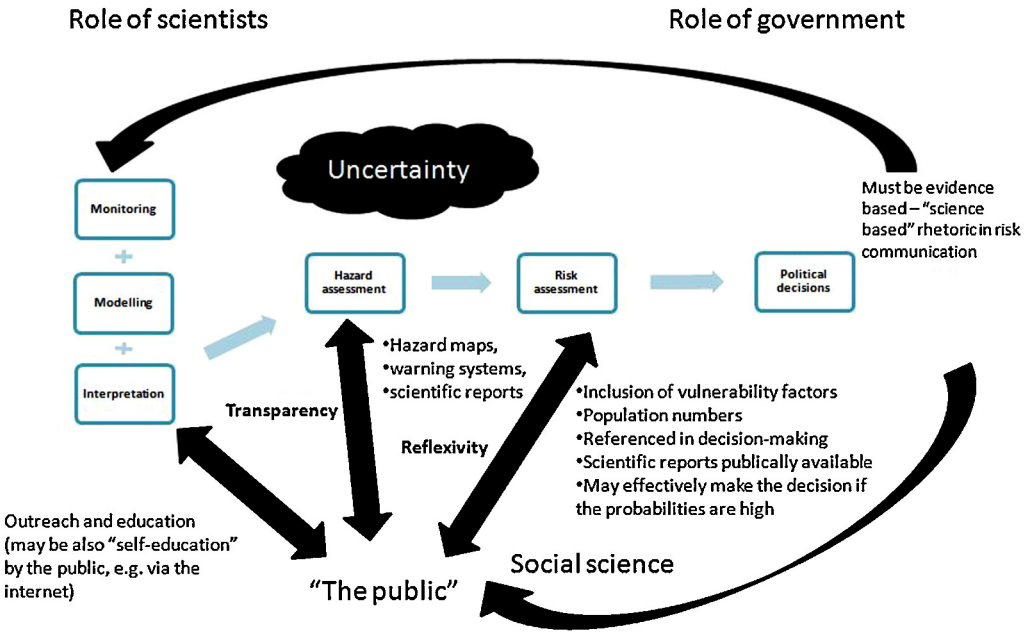

Fig. 2 – Completed schematic for science and policy in volcanic context.

there was sometimes a lack of clarity in the public perception of governance – particularly as a result of the colonial context, but also because of the influx of residents from other islands. They also show that colonial governance of Montserrat caused significant complications in the way that volcanic risk was managed and led to some challenges for scientists both in their reporting structures and in handling the public response to their advice. The very high stakes involved, particularly early in the eruption when the uncertainty was high and many more people lived close to the volcano, demonstrate the importance of establishing advisory pathways in government that can be adapted to low-probability events (Sparks, 2007).

The eruptions on Montserrat between 1995 and 2010 involved an intense process of negotiation between scientists, policymakers and the public. This negotiation concerned lives, livelihoods, political motivations, colonial tensions, scientific interpretations, institutional differences and local culture. Many of these issues would have been easier to manage had

Table 1 – Summary of issues raised in the paper. White denotes scientific issues; light grey, science–policy issues and dark grey refers to issues that are scientific, political and societal.

Inference	Evidence	Implication
• There are geographical variations in the resources and expectations of volcanologists	Interviews; Haynes (2005); Aspinall et al. (2002)	Sensitivity and respect between scientists, even where they disagree, is critical in a crisis
• Volcanologists vary in their identification with local political and economic challenges, and their emotional responses	Interviews; Haynes (2005); Pattullo (2000)	Volcanologists and social scientists have to be aware of this possibility in themselves and others
• Different disciplines may have conflicting interpretations of the evidence. Consensus may be difficult to achieve	Interviews; field notes; Aspinall et al. (2002)	Methods such as expert elicitation and structured discussions are important in risk management where there is no consensus
• Contractual operation of a volcano observatory can produce challenges for existing institutional structures	Interviews; Aspinall et al. (2002)	There is a need for flexible institutional structures to manage long-term volcanic eruptions
• Decisions in volcanic eruptions are very heavily dependent on science, meaning that scientists may be blamed for poor decisions even when they did not explicitly take them	Interviews; survey data Donovan and Oppenheimer (2012); Haynes (2005)	Roles should be clearly delineated, but where there is overlap or conflict, the uncertainty inherent in scientific advice has to be communicated
• Complex political systems can create significant challenges, such as knowing who to report to first and who is responsible for which aspects of risk management	Interviews; Haynes (2005); Donovan and Oppenheimer (2012)	Scientists with monitoring responsibilities should ensure that they are familiar with the details of government structures at all times. External scientists need to be aware of this issue when entering a new situation
• There are cultural differences between groups of scientists from different regions and between scientists and populations	Interviews; field notes.	Careful communication and awareness of potential culture clashes might aid communication within and beyond the scientific community
• Advisory groups may have a role in persistent eruptions. The SAC provide a level of continuity and a different perspective that is valuable to the public and local officials	Interviews; documentary evidence	The involvement of several groups of scientists may be helpful, if everyone involved is aware of their particular role and remit
• Politicians and local officials frequently perceive priorities, the important factors and potential consequences differently from scientists	Interviews, field notes	Interdisciplinary work *involving social and political scientists* should be an integral part of crisis management
• Channels for scientific advice are most effective when they are built on personal trust rather than a report	Interviews	Advisory mechanisms should be in place even when the volcano is quiet, and risk assessments should be communicated to governments both on paper and in person where possible
• Risk communication is a dialogue: people respond more positively if they feel that they can relate to those giving the warnings	Interviews; documentary evidence; field notes	Perceived empathy and listening to residents' concerns may aid the risk communication process
• Risk communication directly between scientists and the public was very much appreciated on Montserrat	Haynes (2005); interviews	Scientists are highly trusted in many places and may be the best source of information
• Trust is dependent on transparency	Interviews; Haynes (2005)	Intelligent publics appreciate being trusted by their advisors
• Local sensitivities and geographical factors including migration may introduce complexity	Interviews	Modes of communication should be reviewed regularly in the context of social changes

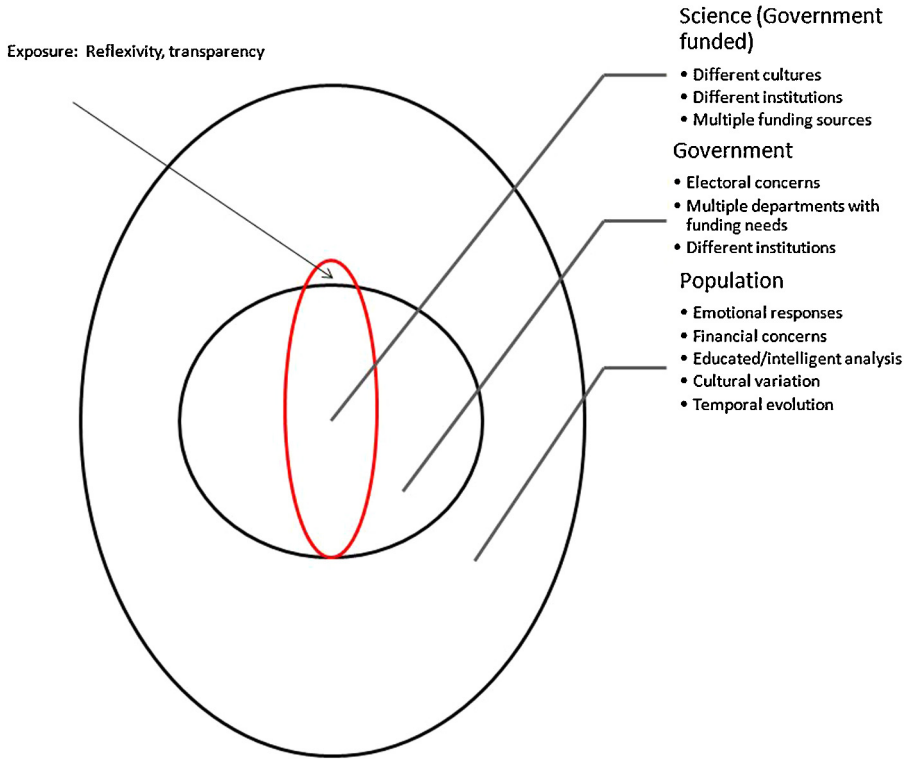

Fig. 3 – "Nested caldera" conceptual model for the role of scientists in disasters.

an observatory been in place prior to the eruption, with scientists who were known to the local officials. Nevertheless, it is likely that a small island observatory would have required assistance in a crisis, and different groups of scientists would be involved. Disciplinary and cultural differences play a key role in the negotiation of dialogue during crisis advice, even where methods are deployed to harmonise the scientific opinion (Aspinall et al., 2002). Scientists have emotional and personal responses to disasters and to the pressure of the public and political demand for knowledge that does not exist. This context can present challenges in communication, especially where a third party is mediating information (as occurred early in the eruptions). Newhall et al. (1999) developed some guidelines for crisis management, and this study affirms those suggestions. It would add to them the need for scientists to reflect regularly on their activities and context, and to ensure that they are familiar with local government structures and cultural sensitivities prior to arrival at a crisis, as suggested in Fig. 2. Social scientific input would aid this. Local institutional structures, cultural awareness and other place-based knowledges may be critical in the rapid development of effective advisory practices. The linear model thus significantly oversimplifies the process of risk management. The broader results we have described are summarised in Table 1 and Figs. 2 and 3.

We suggest, based on the experience of Montserrat, that instead of fighting for a top-down process in which scientists have knowledge and people must respond unquestioningly, or focussing too closely on a bottom-up approach that denies the importance of scientific input, that greater transparency and reflexivity might aid the process of risk assessment and management. Transparency does not only involve reports of activity and monitoring data, but also personal interaction with the public and respect of the public. In particular, the limitations of the science must be clear – this was noted early in the eruption on Montserrat and appreciated greatly by interviewees (see also Haynes et al., 2008). It is important to put numbers on risk, and acknowledge the uncertainties on the numbers – but it is also important to discuss different types of uncertainty. Frequently, the uncertainties on scientific risk assessments are so high that people do not take them seriously (if they look at them!), and this can discourage scientists from such reports. However, the critical component here is social uncertainty – a form of indeterminacy (Wynne, 1992; Hinchliffe, 2001; Donovan et al., 2012b): the safety of the population is no longer certain, potential impacts are not well understood, the consequences of not evacuating may be high and the behaviour of the population cannot be predicted easily. In addition, scientists and decision-makers themselves may be uncertain and concerned about how a population will react to a "false alarm", fearing recriminations and refusal to cooperate with future warnings that may be necessary. The impact of social context and expectations on scientists may produce anxiety, but can also be mobilised – if managed reflexively and transparently.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.envsci.2013.08.009.

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